Magnetic Circular Dichroism in the X-ray Absorption Spectra of the CMR Compound, $Yb_{14}MnSb_{11}$

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This work is part of ongoing investigations into the magnetic and electronic properties of the rare-earth transition metal Zintl phases $A_{14}MnPn_{11}$ (A = Eu, Yb; Pn = Sb, Bi) at the Advanced Light Source. We have recently obtained exciting new results from magnetic circular dichroism investigations of the $Yb_{14}MnSb_{11}$ system. Specifically, we have used magnetic X-ray circular dichroism as an element specific probe into the nature of the magnetic moment in this system with the intention of exploring the proposed half-metallic nature of this compound and its related substitutional analogues.

The term half-metal arises from theoretical predictions made by R.A. de Groot et al based on band structure calculations of the ferromagnetic Heusler alloy NiMnSb.[1] These calculations proposed a new phase of matter that displays separate electronic properties for majority-spin and minority-spin electrons. Specifically, one electron spin population is metallic and the other is insulating. Such a material, (possessing 100% spin polarization of the conduction electron) would hold significant technological potential as a single-spin electron sources for spintronic devices, data storage applications, and high efficiency magnetic sensors.[2]

The materials we are studying are new compounds that belong to a class of materials called transition-metal Zintl phases. These compounds are isostructural to $Ca_{14}AlSb_{11}$ and crystallize in the tetragonal space group $I4_1/$ acd (Z = 8).[3-5] The $Yb_{14}MnSb_{11}$, $Yb_{14}MnBi_{11}$ and $Eu_{14}MnSb_{11}$ analogues are each reported to order ferromagnetically at 56 K, 58 K and 28 K, and 92 K, respectively.[3-5] $Eu_{14}MnBi_{11}$ is an antiferromagnet with a Néel transition at T_N = 32 K.[5] Each of these materials exhibit a large resistance drop associated with their unique magnetic ordering temperature. This behavior is attributed to colossal magnetoresistance effects, and could help support the proposal made by Pickett and Singh of a correlation between half-metallicity and colossal magnetoresistance.[6] These systems are ideal for investigations into the links between magneto-resistance, magnetic moment and half metallic behavior.

The ability to perform magnetic circular dichroism experiments on the EPU has allowed us to probe the dichroic characteristics of Mn in the $Yb_{14}MnSb_{11}$ system during experiments recently performed on beamline 4.0 of the ALS. Figure 1 shows the results from magnetic circular dichroism experiments on the Mn L_{II} and L_{III} edges of $Yb_{14}MnSb_{11}$. The inset is a high-resolution spectrum of the L_{III} edge showing a dramatic dichroism effect, which is confined to one sub-component of the Mn L_{II} edge. The difference in intensity upon change of helicity is greater than 30%, and is strong evidence of a significant moment being present on the Mn; in contrast no such dichroic effect was observed in either the Yb or Sb edges. More detailed analysis and modeling of the observed data is currently in progress.

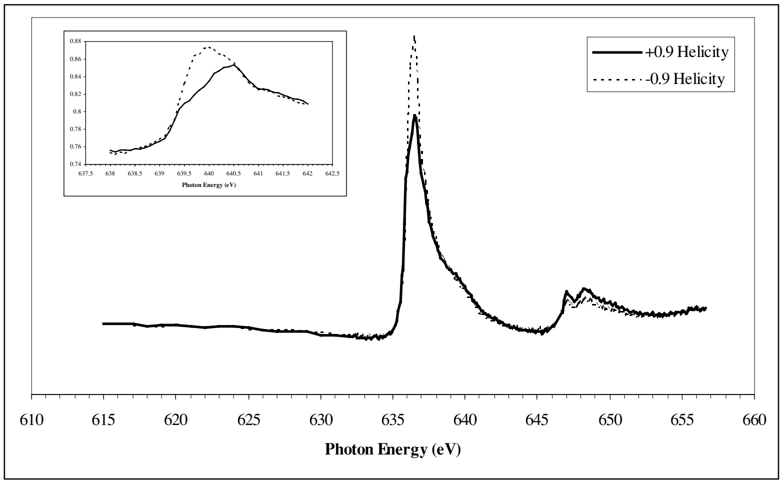

Figure 1

These results provide strong encouragement for further study of this system, and significant motivation to extend this work on beamline 4.0 to a wider range of complementary substitution analogues displaying more complex magnetic behavior. Our initial research proposal has focused primarily on the rare-earth analogs because of their significant magnetoresistance behavior, but influence of varying environments on the Mn dichroism presents an intriguing study. The Eu analog is known to have a contribution from the unpaired spins of the Eu^{2+} cation to the bulk magnetic moment, but little is know about how significant this contribution is to the overall magnetization. In addition, the bulk of the work on these transition-metal Zintl phases has been performed on the alkaline earth analogs with some very surprising differences being shown between their comparable rare-earth analogs. The Yb^{2+} cation and Ca^{2+} cation have approximately equivalent radii, but the comparable $A_{14}MnPn_{11}$ analogs have shown considerable differences in bulk properties. It would be intriguing to investigate how the Mn dichroism is affected by the change of cationic or anionic environment in these additional systems.

Magnetic circular dichrosim measurements of constituent core level peaks offer unique insight into an effect with potentially far reaching commercial applications. Our data from 4.0 has yielded significant information about the origin and environment of the magnetic moment in $Yb_{14}MnSb_{11}$. We are continuing to address new questions that have been raised by our recent results, and are extending our experiments to explore further the wide range of magnetic behavior displayed by this family of materials. This will enable us to significantly improve our understanding of these complex magnetic systems and of the link between half-metallic and magnetoresistive behavior.

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